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Description of an Infrared Zoomcollimator

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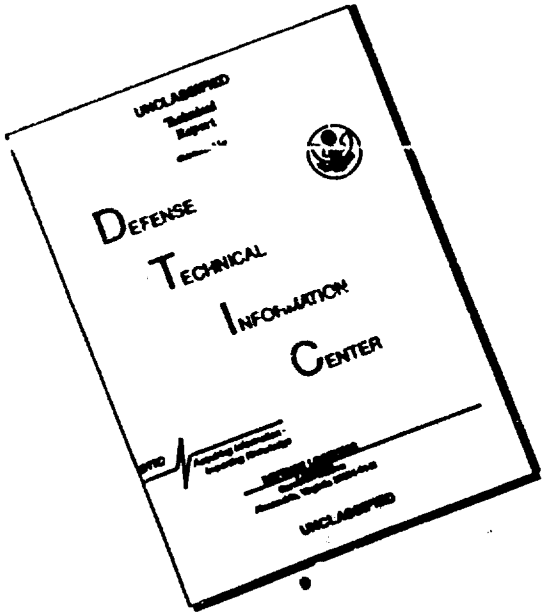

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ABSTRACT (ONGERUBRICEERD)

The performance of thermal imagers is generally tested by means of test targets, put in the focal plane of a collimator. For MRTD measurements bar targets are used with a certain frequency and variable temperature contrast. The zoomcollimator, described in this report provides a variable spatial frequency, which is more comparable to the range variation of a target in the terrain with certain size and temperature contrast. In the focal plane also a line source and a circular source with variable temperature contrast can be used, in order to measure the MRTD in an objective way conform the method, developed at TNO-FEL.

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SAMENVATTING (ONGERUBRICEERD)

De prestatie van warmtebeeldcamera's wordt over het algemeen gemeten met behulp van test-objecten welke in het brandvlak van een collimator worden geplaatst. Voor MRTD metingen worden balkenpatronen gebruikt met een bepaalde frequentie en variabel temperatuurcontrast. De zoomcollimator. beschreven in dit rapport voorziet in een variabele spatiële frequentie, welke meer vergelijkbaar is met de afstandvariatie tot een doel in het terrein met een zekere afmeting en temperatuurcontrast. Bij gebruik van een lijnbron en een circulaire bron met variabel temperatuurcontrast kan de MRTD op objectieve wijze worden gemeten conform een op FEL-TNO ontwikkelde methode.

CONTENTS

1 INTRODUCTION

The performance of a thermal imaging sensor is generally measured by using a collimator system with different kinds of targets in its focal plane. Because of the fact, that thermal imagers are dealing with 2 types of resolution: geometrical- and thermal resolution, two kinds of targets are used, one with variable spatial frequency information and one with temperature gradients.

The Minimum Resolvable Temperature Difference (MRTD) is a performance parameter, widely in use because of its capability to predict ranges, which is a combination of spatial and thermal resolution. It is a subjective parameter including the observer, who has to judge if a certain 4-bar pattern target can be distinguished at a certain temperature difference between bars and background (see e.g. ref [1] and [2]).

A complete MRTD measurement at a number of spatial frequencies and a number of observers is very time consuming. For this reason, a new method was developed, which excludes the observer from the direct measurement and replaces him by a model.
Furtheron the spatial resolution is measured by means of the system Line Spread Function (LSF), delivering the Modulation Transfer Function (MTF) and the Noise Equivalent Temperature Difference (NETD) (see ref [3]).
For this purpose a line source is used for the LSF and a circular source of certain size for geometry- and NETD measurement. The display is partly (about 1/5) projected onto a CCD camera of which the images are processed in a PC. Care is taken that all signals stay within the linear part of the dynamic range.

In order to further simplify the system, it was decided to build a portable collimator which can be used in the field. The collimating component was changed from reflective (30 cm aperture) to refractive (15 cm aperture) with the advantage that the imager pupil can be positioned closely to the collimator pupil.

Another idea was integrated into the new collimator concerning a zoom capability. This meant that the two targets (line and circle) can be kept for a variety of imagers with different fields of view. Furthermore, if the circle target is replaced by a 4-bar target, zooming in and out means variation of range, keeping the temperature difference constant.

In fig. 1 the classical method of subjective MRTD measurement is indicated at position A; at frequency f_0,ΔT_0 is varied until the observer decides upon the limit of recognition.
At position B the temperature difference ΔT_1 is kept constant and the observer varies the spatial frequency, while the same target is kept, which is a great advantage. Target changing easily causes temperature instabilities and it cost more time.

The development of the zoomcollimator was carried out at TNO-FEL as a project with "basic funding". The work was carried out in 1992. The mechanical construction was realized by Jan ten Donkelaar and the electronics by Wim van Bommel and Marco Roos. The latter also provided the software for system control.

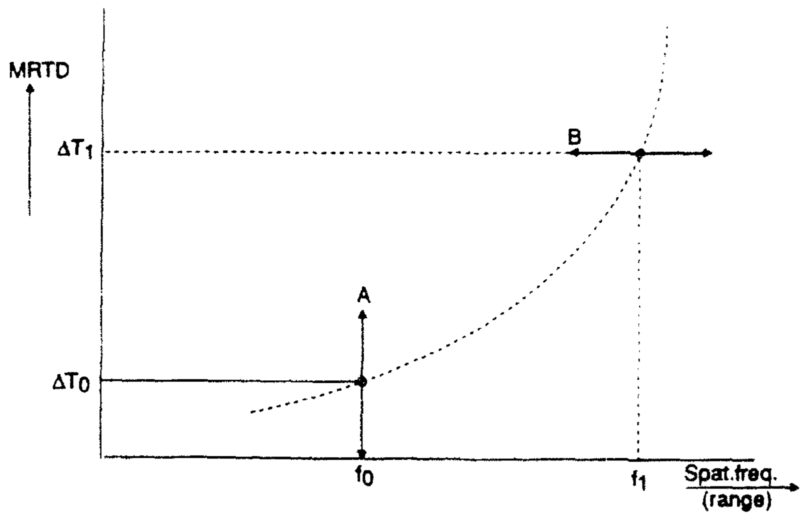


Fig. 1: Description of MRTD measurement

2 DESCRIPTION OF THE EQUIPMENT

Two requirements were set to the portable collimator:

- pupil diameter about 150 mm
- system length less than 1500 mm.

The total weight should be limited to about 50 kg, otherwise the tripod on which the collimator has to be mounted will be too bulky.

The pupil diameter should remain its value for all focal lengths, which means increasing numerical aperture for shorter focal lengths.

The principle of the zoomcollimator is drawn in fig. 2. Lenses L_1 and L_4 are fixed lenses with focal lengths of 1100 resp. 320 mm. F is the focal plane. Positions A, B and C are indicated for lenses L_2 and L_3 for effective focal lengths from ½ up to 2 times the focal length of L_1. The focal length of L_2 is -100 mm which means that P, which is the focal point of L_1 is imaged towards P' in situation A and C and towards P" in situation B. Lens L_3 makes the beam always parallel by keeping its focus from P' to P" and back again. Lens L_4 is identical to lens L_3.

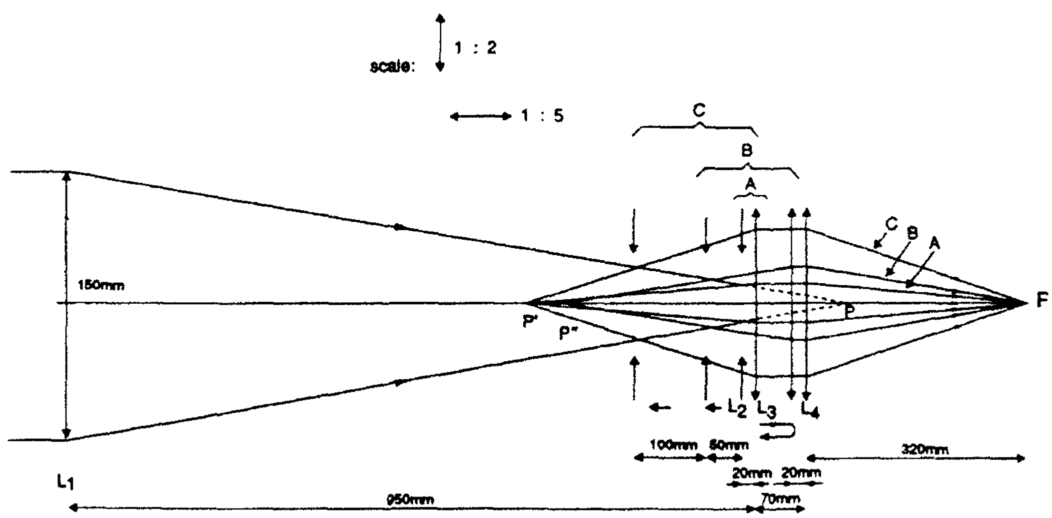


Fig. 2: Schematic principle of IR-zoomcollimator (length 136 mm)
L_1 = fixed lens (f = 1100 mm) L_4 = fixed lens (f = 320 mm)
L_2 = moving lens (f = -100 mm) L_3 = moving lens (f = 320 mm)
System focal length: A: 2200 mm B: 1100 mm C: 550 mm

The negative lens L_2 provides compensation of spherical aberration for all focal lengths below 0,02.10^{-5} mrad which is far below the diffraction limit (0,08 mrad for 10 μm).
The pupil is imaged at appropriate locations from F. The field of view of the collimator is for an unobscured pupil through all lenses for a full pupil diameter of 150 mm respectively 2,34°; 1,77° and 0,52° for the situations A, B and C. The limiting lenses are respectively the 2nd, the 3rd and the 4th lens. If the pupil goes down to 100 mm, the fields of view increase respectively 2,81°; 2,19° and 1,25°. If some vignetting is allowed the fields of view will be greater.

The data for lenses L_2 and L_3 (= L_4) are:

L_2:
- material: germanium; n = 4,004 (= 9,2 μm)
- curvatures R_1 = -223,08 mm R_2 = -869,00 mm
- axial thickness 6,00 mm
- focal length -100,61 mm
- diameter 60 mm

L_3,L_4:
- material: germanium; n = 4,004
- curvatures R_1 = 325,76 mm R_2 = 478,71 mm
- axial thickness 10,00 mm
- focal length 323,54 mm (back focal length 316,08 mm)
- diameter 110 mm

The paraxial positions for lens L_2 for situations A, B and C are:

A: S_3 = 150 mm S_3' = -588,88 mm S_4 = -594,88 mm S_4' = -305,44 mm Magn = 2,020
distance P'-P = 449,44 mm

B: S_3 = 200 mm S_3' = -472,95 mm S_4 = -478,95 mm S_4' = 203,95 mm Magn = 1,007
distance P''-P = 397,95 mm

C: S_3 = 300 mm S_3' = -395,16 mm S_4 = -401,16 mm S_4' = -153,28 mm Magn = 0,503
distance P'-P = 447,28 mm

Lens L_3 is always at 316,08 mm from P'(P'').

All lenses are made of germanium, which implies chromatic aberrations of abou. 0,05 mm diameter. This is sufficiently below the diffraction limit if we limit the collimator between 8 and 12 μm.
Fig. 3 and fig. 4 give pictures of the complete collimator and of a close up of the zoom compartment. The lenses L_2 and L_3 are driven by means of servo motors with driving belts, mounted on the bottom side. Potentiometers provide position information. Electronic circuitry is mounted in the inside compartment, as shown in fig. 4.

The targets are mounted at the backside as plug in units. One unit is provided with a line source, tilted under about 10° from the vertical or horizontal. This wire is heated and has a diameter of 0,03 mm. The second unit is provided with a rectangular, circular or 4-bar source.
The system has 2 connectors, one to the zoomcompartment and one to the targets. The target compartment is provided with a peltier heated or cooled background. The heat is removed at the back side by free convection. The complete system can be mounted on a tripod by means of a standard mounting plate.

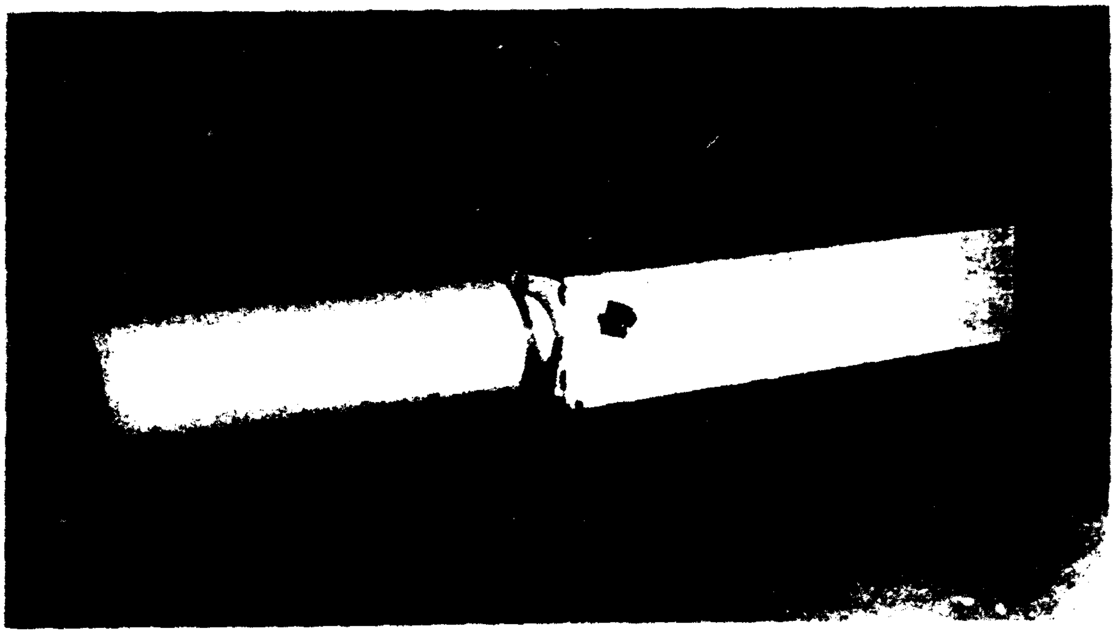


Fig. 3: Complete view of zoomcollimator

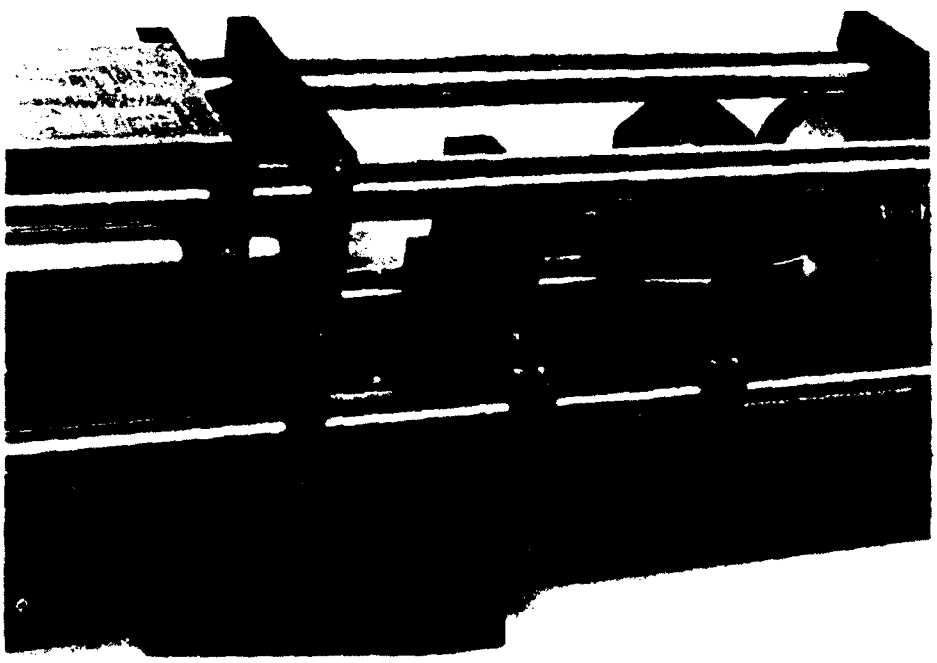
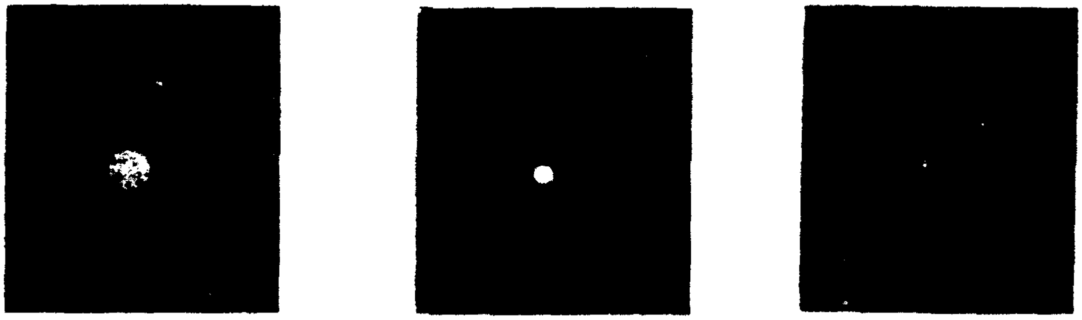


Fig. 4: Inside view of zoomcollimator with lenses L_2, L_3 and L_4

3 EXAMPLES

Some examples of images, taken with an IR 18 infrared imager from Barr and Stroud, are shown in fig. 5 and fig. 6.

Fig. 5 shows the circular source for the 3 situations A, B and C. Fig. 6 shows the line source for the same situations. The total transmission of the 4 germanium lenses was measured to be 0.65. All lenses are provided with a single layer anti-reflection coating for a wavelength of 10 μm. The heating and cooling of the background plate is going at sufficient speed to perform a subjective MRTD measurement. The read out of the temperature differences with Pt resistors was calibrated with a second calibrated source from Electro Optical Industries and a radiometer with sufficient resolution.



A
f = 2200 mm

B
f = 1100 mm

C
f = 550 mm

Fig. 5: Images of a circular source; $\Delta T = 6^{\circ}C$; Directly taken with IR 18 thermal imager

a) near vertical

b) near horizontal

Fig. 6: Images of a tilted line source via CCD camera with 5 x magnification;
Picture taken with IR 18 thermal imager

4 CONCLUSIONS

The development of an Infrared Zoomcollimator has been very successful. The instrument creates new possibilities to carry out faster, more repeatable and more accurate performance measurements of IR sensors, in the field, in the factory and in the laboratory. The most relevant system parameters like Signal Transfer Function, Modulation Transfer Function, Noise Equivalent Temperature Difference as well as Minimum Resolvable Temperature Difference and Noise Equivalent Irradiance can be measured, especially when data acquisition is done by means of a PC with frame grabber. By means of the zoom-capability of the collimator, the possibility has been created to measure directly the range at which a 4-bar target with given temperature difference can be recognized. The Physics and Electronics Laboratory, TNO-FEL is ready to provide quotations on the device.

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THE PERFORMANCE OF THERMAL IMAGERS IS GENERALLY TESTED BY MEANS OF TEST TARGETS, PUT IN THE FOCAL PLANE OF A COLLIMATOR. FOR MRTD MEASUREMENTS BAR TARGETS ARE USED WITH A CERTAIN FREQUENCY AND VARIABLE TEMPERATURE CONTRAST. THE ZOOMCOLLIMATOR, DESCRIBED IN THIS REPORT PROVIDES A VARIABLE SPATIAL FREQUENCY, WHICH IS MORE COMPARABLE TO THE RANGE VARIATION OF A TARGET IN THE TERRAIN WITH CERTAIN SIZE AND TEMPERATURE CONTRAST. IN THE FOCAL PLANE ALSO A LINE SOURCE AND A CIRCULAR SOURCE WITH VARIABLE TEMPERATURE CONTRAST CAN BE USED, IN ORDER TO MEASURE THE MRTD IN AN OBJECTIVE WAY CONFORM THE METHOD, DEVELOPED AT TNO-FEL.

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